Summary of Tevatron Lattice/Dispersion Studies

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This is a summary of the matching measurements, conclusions, and recommendations made for the P1 and A1 beamlines. Slides from a more detailed presentation can be found in the document database as document number 725.

Motivation

The flying wires in the Main Injector and Tevatron (as reported by the SDA) show an emittance dilution of about 10 π-mm-mr in the vertical plane and none in the horizontal plane for proton injection. For pbar injection both the horizontal and vertical wires indicate on the order of 8-10 π-mm-mr growth. We wanted to determine if the source of this growth was due to lattice or dispersion mismatch.

Previous studies (Syphers and Annala) with the Tevatron skew quads showed that the vertical dispersion in the Tevatron could be reduced at F0 with different skew quad settings. They showed this lead to a reduction in the round trip emittance dilution.
In addition, the P1 line design incorporated a set of 4 quad rolls to de-couple the x-y motion at the Tevatron injection point.

Due to installation issues, these quads were not rolled during installation. We propose to rectify this situation

Conditions and Measurements for P1

Prior to the study operations tuned up forward and reverse injection into the Tevatron using the standard 30 bunches. The program I91 was used to collect BPM flash data, BLM readings, magnet current readbacks (at extraction time), beamline multiwire profiles, intensities (DCCT and toroid) , and RF frequency reading from the beamline as well as both MI and Tevatron. Data for at least 4 settings were taken from one bump measurements from dipoles in the MI and beamline. The frequency range of +/- 200 Hz (in steps of 50 Hz) was used for dispersion measurements on both first turn and Tevatron circulating beam on central orbit. We kept track of losses in the Tevatron and beamline and do not include data were the beam is significantly scrapped. In addition, we measured the beam profiles in the beamline. The input emittance and momentum spread were adjusted in the model to match the measured beam sigmas. The resultant values are consistent with expected parameters. The predicted beam size was propagated from the MI thru F-sector. These were compared with expected beam size as predicted from the Tevatron injection lattice MAD model.

P1 Measurement Results

Both horizontal and vertical differential orbits from bumps in the MI and start of the P1 line beamline agree with the model (using measured currents) for the P1 multiwires and Tevatron BPM's. The response of each detector over the range of the bump amplitude was measured to find scaling error or noisy signals. The beamline BPM were not stable enough to use for data analysis (thank goodness for multiwires). The horizontal differential orbit from the MI extraction Lambertsons (rolled) agreed well with the multiwires and Tevatron BPM's (in both planes).

We compared the measured first turn lattice with the model of the Tevatron injection lattice. The comparison was quite good and does not appear to lead to any emittance growth.

The comparison of the circulating and first turn dispersion showed a mismatch in amplitude and phase.

Roll angles were determined for Q707 (-1.7 deg) and Q709 (-2.0 deg) to match the first turn dispersion with the current Tevatron circulating dispersion. In addition, the roll angles for Q706 (-0.65 deg), Q707 (-2.6 deg), Q708 (-0.05 deg), and Q709 (-1.25 deg) were determined to completely cancel the first turn vertical dispersion into the Tevatron. Both solutions did not alter either the lattice match or the horizontal dispersion match into the Tevatron. The coupling terms from the beamline at the Tevatron injection point were cancelled.

Conclusions from P1 Measurements

The lattice functions between the MI and Tevatron appear to be matched. There does not appear to be any dilution from steering errors (Operations tuned up closure to shot standards prior to study). There does not appear to be any horizontal dispersion mismatch. For the settings of the Tevatron skew quads used in the study (nominal operating values) there is a vertical dispersion mismatch of ΔDeq = 1.25 m. For a momentum distribution of $\sigma_p/p \sim 0.5 \times 10^{-3}$ we get a calculated emittance growth of $\Delta\varepsilon_N \sim 1.5$ to 1.9 π–mm-mr. <u>This does not explain the observed growth from the flying wires.</u>

Measurements for A1

Operations tuned up reverse injection on the pbar helix prior to the study. The same type of data was taken for this transfer.

A1 Measurement Results

From comparison of "nominal" conditions taken at various points during the study, we found the A1 BPM's to be unreliable for any serious data analysis and the Tevatron BPMs show a, yet to be explained, systematic offset as compared with one of the "nominal orbits". The comparison of the multiwire centroids was very good. The measured Tevatron and MI BPM response and beamline multiwires to both horizontal and vertical differential orbits started in the Tevatron (E2) agreed well with the model. For the orbit distortions started at the Tevatron end of the A1 line, the beamline multiwires agree well with the model, but there were some discrepancies in the MI response to horizontal kicks. The horizontal data could be made to agree better by adjusting Q902 by about 25%. This is not understood and only affects the MI BPM data.

The measured lattice parameters show about a 20% beta wave in the vertical plane. The agreement in the horizontal is on the order of 10%.

Circulating dispersion on the helix was measured using VFKNOB. A vertical dispersion wave of about ½ meter was seen. The horizontal dispersion matched the model prediction. The dispersion measurement for reverse injection was measured for the Tevatron, beamline and MI. A residual vertical dispersion of about ¼ meter was seen in the MI. Propagating this dispersion in the pbar direction (starting with zero vertical dispersion in the MI) showed a mismatch between the vertical dispersion generated in the A1 line and the Tevatron circulating dispersion. Again, the horizontal dispersion was matched.

Roll angles were determined for Q906 (-0.8 deg), Q907 (-1.1 deg), Q908 (0.0 deg),and Q909 (-0.3 deg) to match the first turn dispersion with the current Tevatron circulating dispersion on pbar helix. In addition, the roll angles for Q906 (-0.08 deg), Q907 (0.67 deg), Q908 (0.03 deg), and Q909 (-0.05 deg) were determined to completely cancel the first turn vertical dispersion into the Tevatron. Both solutions did not alter either the lattice match or the horizontal dispersion match between the MI and Tevatron. The coupling terms from the beamline at the Tevatron injection point were cancelled.

Conclusions from A1 measurements

The lattice functions between the Tevatron and MI appear to be sufficiently matched as not to contribute significantly to any emittance growth. Since the closure was performed in the tune up, any residual steering error was small enough as not to contribute to emittance growth. The horizontal dispersion between the two machined appear to be well matched. But, the vertical dispersion did show a smaller mismatch than for proton injection. We see a ΔD_{eq} of about ½ m and with a momentum spread of $\sigma_p/p \sim 0.5E\text{-}3$ the emittance growth is $\Delta\varepsilon_N \sim 0.5\ \pi$–mm-mr. <u>This is not significant and does not explain the observed emittance growth.</u>

Recommendations

The roll angles for Q707, and Q709 should be installed before the shutdown to further reduce emittance growth and verify the procedure. When the vertical dispersion in the Tevatron is fixed during the shutdown, the roll angles should be modified as described (and as initially designed).

An additional systematic study of proton injection looking at the Tevatron flying wire response to known injection steering errors, initial emittance, initial momentum, and helix size, VFKNOB settings, should be performed (either before or after rolling quads).

An additional detailed and systematic measurements of round trip emittance growth from both the central orbit and pbar helix should be performed to understand the measured emittance growth. These would entail dependence on initial emittance, helix amplitude, extraction on central orbit, steering errors into and out of the Tevatron, momentum dependence on central orbit, flying wire response to momentum spread (using VFKNOB to fuzz the beam after injection), etc.

The quads in the A1 beamline should be rolled to decouple the x-y motion and cancel the vertical dispersion into the Tevatron. The timing of this modification needs further consideration but should not be done before the additional round trip emittance study.